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The Future of Nuclear Power in the United States: Economic and Regulatory Challenges

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THE FUTURE OF NUCLEAR POWER IN THE UNITED STATES: ECONOMIC AND REGULATORY CHALLENGES[1]

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ABSTRACT

This paper examines the economic and regulatory challenges that must be faced by potential investors in new nuclear power plants in the United States. The historical development of the existing fleet of over 100 nuclear plants and their recent performance history are discussed. The pattern of re-licensing of existing plants and the implications for the role of the extended operation of the existing fleet in the overall electricity supply portfolio over the next 50 years is examined. The economic competitiveness of investments in new nuclear power plants compared to investments in alternative base load technologies is discussed under a variety of assumptions about construction costs, fuel costs, competitive and economic regulatory environments and various levels of carbon emissions prices affected competing fossil-fueled technologies. Federal government efforts to facilitate investment in new nuclear power plants, including streamlined licensing procedures and financial incentive provided by the Energy Policy Act of 2005 are discussed. These regulatory changes and financial incentives improve the economic competitiveness of nuclear power. First mover plants that can benefit from federal financial incentives are most likely to be built in states that continue to regulate generating plants based on cost-of-service principles, transferring construction cost and operating performance risks to consumers, and where there is room on existing sites to build additional nuclear capacity. Once federal financial incentives come to an end lower and more stable construction costs combined with carbon emissions charges are likely to be necessary to make investments in new nuclear plants significantly more attractive than investments in pulverized coal plants. Unresolved waste disposal policies and local opposition to new nuclear plants are likely to represent barriers to investment in new nuclear power plants in some areas of the country.

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[1] This paper is based on a presentation that I made at the conference "Is Nuclear Power a Solution to Global Warming and Rising Energy Prices?" sponsored by the American Enterprise Institute in Washington, D.C. on October 6, 2006. This paper relies heavily on research performed in conjunction with my colleagues on the MIT Interdisciplinary Study *The Future of Nuclear Power* (MIT 2003), subsequent research that I have performed in more recent developments, and on the analysis contained in the International Energy Agency's *World Energy Outlook 2006,* Chapter 13 (IEA 2006) for which I was an advisor. The interpretations and conclusions contained in this paper are my own.
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INTRODUCTION AND OVERVIEW

Nuclear power now accounts for almost 20% of the electricity produced in the United States. However, the last nuclear power plant completed in the U.S. entered commercial operation in 1994 and no new nuclear plants have received construction permits since 1979. If the existing fleet of nuclear plants were to run only until the end of their initial license periods, the supply of electricity from nuclear power would begin to decline in about 2015 and reach zero in about 2030. Under current economic conditions, these plants would be replaced primarily with a mix of coal and natural-gas fired plants. However, a large fraction of the nuclear plants now operating have received, applied for, or intend to apply for extensions on their operating permits that would allow them to continue operating for an additional 20 years. If all existing plants are re-licensed this will extend the date when nuclear electricity supplies begin to decline until about 2035 and fall to zero in about 2050, absent construction of any new nuclear power plants.

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Even if all existing nuclear plants are re-licensed for 20 addition years of operation, the fraction of electricity produced with nuclear power in the U.S. will decline monotonically over the coming decades if investment in new nuclear generating plants is not forthcoming. Additional electricity supplies required to balance supply and demand in the next 25 years will come primarily from coal and gas-fired power plants given current cost expectations and in the absence of a "price" being placed on CO_2 emissions.

The decision of most nuclear plant operators to apply for extensions of their initial operating licenses reflects several factors. First, the performance of the existing fleet of nuclear plants has improved dramatically over time in terms of capacity factors, operating costs, and safety indicators. Second, the price of alternative fuels and the wholesale market price of electricity have increased dramatically. Third, the incremental capital costs required to extend the life of existing plants to meet license renewal requirements is typically small compared to the total cost of a new coal or natural gas combined cycle (CCGT) plant. On a going forward basis, life-extensions for existing plants are now very cost-effective and, for merchant plant owners, quite profitable. These developments also favorably impact the relative economic evaluation of investments in new nuclear plants compared to base load alternatives. However, on a going forward basis private investors in new nuclear plants must expect to recover both their operating costs and the much higher capital costs of building a new plant from revenues earned from electricity produced by the plant.[3] The necessary revenues must come either from sales of power at market prices in states that have adopted competitive market models or through regulated retail prices determined through the regulatory process in states where generation investments are still subject to regulation.

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[3] The economic calculus may be different for state-owned firms and I will not discuss such firm here.

It is worth noting that two actual and potential institutional changes have taken place since the existing nuclear fleet was built that will effect the economic evaluations of potential private investors in new nuclear plants. First, in many regions of the country the electric power sector has been restructured and the generating segment deregulated (Joskow 2006a). In these regions, investments in new nuclear plants would be on a merchant basis and face standard market risks and rewards associated with uncertain construction costs, operating performance, and changes in market conditions. Even in states where generation investments are still regulated, long-term commitments for new generating capacity must often be put out for competitive bids and both long-term power supply contracts and generating plants built by vertically integrated utilities will be subject to performance incentives that will shift more cost and performance risk to investors than in the past. These changes work against capital intensive generating technologies like nuclear power because they increase financing costs. Second, the prospect of mandatory controls on CO_2 emissions makes it possible that in the not too distant future, CO_2 emissions will incur a price either in the form of a "green tax" or, more likely, payments for (or opportunity costs of allocated) CO_2 emissions permits under a cap and trade system as is the case in Europe. Placing a significant price on CO_2 emissions would make investments in nuclear power more attractive in both competitive and cost-based regulated environments.

THE EXISTING NUCLEAR FLEET

There are 104 commercial nuclear power plants operating in the U.S today. Eleven nuclear plants were shut down during the 1990s, in several case, for economic reasons, prior to the end of their licensed operating lives. However, no operating nuclear plants have been shut down since 1998. The development of the existing fleet of nuclear plants confronted numerous problems along the way that continue to affect business perceptions about potential investments in new nuclear plants. These problems included: lengthy licensing processes, large construction cost overruns, long construction periods, poor availability, high operation and maintenance costs, the need for early replacement of steam generators and other major pieces of equipment, public opposition to construction in several regions of the country, and an accident at the Three Mile Island (TMI) nuclear plant in 1979 that had an adverse effect on public perceptions of nuclear power safety. This accident also led to increased construction costs for nuclear plants then under construction due to post-TMI regulatory delays and plant design changes. Moreover, the federal government has yet to deliver on its promise to take procession of spent fuel and other nuclear waste and develop interim and permanent storage facilities for it. Several utilities completing nuclear power plants during the 1980s and early 1990s faced serious financial difficulties as state regulators sought to "disallow" portions of their plants' construction costs from the regulated prices for electricity they were permitted to charge. At least one utility went bankrupt and others came close.

Moreover, during the late 1980s and 1990s, natural gas prices fell dramatically and price forecasts made during this period for future natural gas and coal prices indicated that real (controlling for general inflation) natural gas prices would rise slowly and real coal prices would continue to fall slowly of the next 25 years (EIA AEO 1998, page 2). As a result, investment in natural gas combined-cycle gas turbine technology (CCGT) was perceived as being a lower cost, lower financial risk, and more politically acceptable base load generation alternative to both coal and nuclear generating technology, especially as competitive wholesale electricity markets began to emerge. Between 1997 and 2005 over 200 GW on new "on grid" generating capacity was added in the U.S. (Joskow 2006a), most of it fueled by natural gas. No new nuclear plants have been ordered in the U.S. since 1978. Orders for 124 nuclear units were eventually cancelled. Nearly ten years ago, the 1998 EIA Annual Energy Outlook forecasted the gradual demise of nuclear power, projecting that 24 nuclear plants would retire before the end of their license expiration dates and that 65 plants would retire before 2020 (EIA AEO 1998, pp. 54-56).

However, the performance of the existing fleet of plants has improved dramatically over time and the economics of both life-extension and new investment have changed significantly in the last few years. As displayed in Figure 1, real non-fuel operation and maintenance costs have fallen (on average) from about 20 mills/kWh in 1992 to 12.5 mills/kWh in 2005 (in constant $2003) and total direct real operating costs have fallen from over 27 mills/kWh to less than 17 mills/kWh during this time period.[4] As displayed in Figure 2, plant capacity factors have increased from less that 60% in the late 1980s to close to 90% in the last five years.[5] Various safety indicia have improved considerably as well.[6] These improvements in the performance of the existing fleet of plants, combined with dramatic increases in natural gas prices and wholesale electricity market prices in the last couple of years, have significantly changed perceptions about the

[4] These numbers do not include all of the costs associated with these plants. Various owner's costs including regulatory compliance costs, insurance, training, and general corporate overheads are not reflected in these numbers as far as I can tell.

[5] There is some selection bias in these figures since when poorly performing nuclear plants close before their design lives their poor capacity factors disappear from the data. There is a close relationship between improvements in capacity factors and improvements in "variable" operating costs, since the latter are driven primarily by whether a plant to in commercial service for a period of time rather than by how many kWhs it generates during this time period.

[6] *Annual Report 2005*, Institute of Nuclear Power Operation (INPO), http://www.nei.org/documents/WANO_Performance_Indicators_2005.pdf, accessed December 1, 2006.

remaining economic lives of the existing fleet from what they were only a few years ago. As I have already noted, there have been no plants retirements since 1998 and most of the existing fleet has received, applied for or expects to apply for 20-year extensions on their licenses to bring their licensed operating periods to 60 years. As of November 2006, 47 plants had received license extensions, 9 license extension applications are pending, and another 25 have indicated their intension to apply for license extensions.[7] This will extend the life of the existing fleet of nuclear plants considerably, with significant plant retirements now not beginning until about 2035 and the existing fleet closing down completely by about 2050 (assuming no further life extensions). In the process of making investments to extend plant lives, some units are being "uprated" modestly and EIA forecasts that this process will create about 3.2 Gw of additional nuclear capacity from the existing fleet. Another 1.3 Gw of capacity is associated with the refurbishment and return to service of TVA's Brown's Ferry 1 nuclear unit in 2007.

INVESTMENT IN NEW NUCLEAR PLANTS

a. The changing regulatory and competitive environment

The improved performance of the existing fleet of nuclear plants, higher fossil fuel prices, new plant designs that vendors claim will result in lower and more predictable construction costs, a streamlined construction and operating license process, the prospect of future mandatory CO_2 emission constraints, and federal financial incentives created by the Energy Policy Act of 2005, together have had favorable effects on the economic attractiveness of investments in new nuclear plants. In the end, whether or not a company invests in a new nuclear plant will be a commercial decision that turns

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[7] Nuclear Energy Institute, http://www.nei.org/index.asp?catnum=2&catid=343, accessed November 27, 2006.

on the (risk adjusted) economic attractiveness (cost and profitability) of an investment in nuclear power generating capacity compared to investments in alternative generating technologies that can produce equivalent quantities of electricity.

The economic environment in which nuclear investments will be considered by electricity producers has also changed dramatically since the first fleet of nuclear plants was built in the United States. Until the late 1990s most of the nuclear power plants were built by investor-owned utilities which were subject to cost of service regulation and had de facto exclusive geographic service territories where they charged customers regulated prices determined based on cost of service principles that evolved during the 20th century. Regulation insulated these firms from competition from lower-cost generating companies and typically allowed them to shift a large fraction of any construction cost overruns and poor operating performance to consumers through regulated prices. Consumers arguably got the benefits of what was then perceived to be an efficient industry structure built around the assumption that electricity would be supplies most efficiently to a specific geographic area by vertically integrated monopolies subject to price, cost and service quality regulation.

This is not to say that utilities building nuclear plants under traditional regulatory arrangement during the development of the existing fleet faced no risk from poor performance, since some regulatory agencies disallowed what they perceived to be imprudent costs and others introduced incentive mechanisms to stimulate better operating performance (Joskow and Schmalensee 1986). However, it is fairly clear from the record during this time period when companies were frequently applying for rate increases, that consumers bore a large share of the costs associated with construction costs overruns, poor operating performance, and changing economic conditions. This regulatory environment made it possible for many utilities to finance nuclear plants using a relatively low cost of capital. Since nuclear plants were and are more capital intensive than pulverized coal or CCGT technology (absent carbon capture and sequestration faxcilities), this regulatory environment favored nuclear power by reducing the cost of capital, other costs held constant.

This regulatory and competitive environment has changed in many areas on the U.S. In most of the Northeast, portions of the Midwest and in Texas, competitive wholesale electricity markets have been created and competing merchant generators are free to participate as suppliers in these competitive wholesale markets (Joskow 2006a). Wholesale prices for power have been deregulated and as transition arrangements come to an end, retail consumers pay prices that reflect competitive wholesale market prices not prices determined by cost-of-service regulation. (Joskow 2006a). In the first instance, investors bear all construction cost, operating performance, fuel price, and wholesale power market risks, as well as residual regulatory risks associated with a restructuring and deregulation process that is still a work in progress.

These developments in the competitive and regulatory environment change the financial risks associated with nuclear power plant investments in a number of ways. Development costs associated with licensing, site studies and engineering studies, are not recoverable through a regulatory process but must be recovered from market revenues when and if a plant is completed and is operating. Construction cost overruns, major equipment replacement costs, variations in availability and variations in market price will all be risks that the plant investor will bear. Of course, investor can seek to hedge some or all of these risks through contractual arrangements with vendors, construction companies, and forward contracts with market intermediaries and retail consumers. The 1600 Mw nuclear power plant being built by AREVA-Siemens in Finland has hedging arrangements of this kind on both the construction cost and energy sale sides (IEA 2006, p. 352). However, it is unlikely that the long-term contractual arrangements that the owner of the new nuclear plant in Finland has with large buyers of the power supporting the project could be replicated widely in those areas of the U.S. that rely on competitive wholesale and retail electricity markets. Let me note clearly as well, that in a competitive market environment it is the investors who must be convinced about expected construction costs and plant performance parameters and the ultimate cost and profitability of a potential nuclear power plant project in order to get them to invest. Lobbying to convince government official that investment in new nuclear plants represents the lowest cost alternative in regions that have adopted competitive models is not particularly productive.

There are many states in the U.S., however, which have not implemented comprehensive restructuring and deregulation programs for electricity generation (Joskow 2006). Retail prices continue to be regulated, utilities have de facto geographic monopoly service territories where consumers are charged for electricity based on regulated prices, and utilities can assume that prudently incurred generation costs will be passed through in regulated retail prices. In a regulated environment utilities do have to spend a lot of time convincing regulators that their proposed investments would be less costly than alternatives in order to get permission to proceed with the project and to avail themselves of the protections of cost-of-service regulation. In these states lobbying by nuclear suppliers to convince government officials to accept optimistic cost projections may have some value. However, the regulatory environment that prevailed when the existing fleet of nuclear plants was built is also changing and is likely to change further as proposals by utilities to build new regulated “cost-of-service” generation projects increase.

First, many state commissions now require utilities to benchmark proposals to build their own generating plants subject to cost of service regulation against proposals from independent power producers to supply them with equivalent quantities of power under long term contracts. These contracts in turn typically have incentive provisions that place construction cost and operating performance risks on the owner of the plant rather than on the utility buying the power and ultimately on the utility's customers paying regulated retail prices that include contractual payments under purchased power contracts. Accordingly, in order to get permission from a state regulatory agency to build a new plant under cost of service regulation, whether nuclear or non-nuclear, the regulatory agency will have to be convinced that the proposed project will be less costly for consumers than alternatives based on market benchmarks. Moreover, I believe that it is likely that when regulators do allow vertically integrated utilities to build additional plants under cost of service regulation that they will include incentive or performance-based regulation provisions that are not unlike those in long-term purchased power contracts. Specifically, I expect that they will place more of the risk of construction cost overruns and poor operating performance on the utility and less on the utility's retail customers than was the case when the existing nuclear fleet was under construction.

These incentive arrangements will increase the risks faced by utilities compared to the old regulatory regime and increase the cost of capital properly attributed to the project.

b. Life-cycle cost comparisons

This discussion leads naturally to a discussion of what we know about the expected future life-cycle costs of new nuclear power plants compared to pulverized coal and CCGT technology, the two primary baseload alternatives to nuclear, at least over the next 25 years if there is no price places on CO_2 emissions (AEI AEO 2006). Will potential investors view nuclear investments as being the lowest cost or the most profitable base load generation alternative? Here I draw primarily on work done in connection with the *MIT Future of Nuclear Power Study* (2003) and more recent work published by the International Energy Agency (IEA 2006, Chapter 13) in 2006.

There are several primary variables that determine the expected life-cycle costs of alternative generating technologies with a given generating capacity. These are (a) the "overnight" construction cost, (b) the construction period and associated cash flows, (c) financing costs and any associated cash flow constraints, (d) corporate income tax rules, (e) fuel costs and their assumed real rate of escalation over time, (f) non-fuel operation and maintenance expenses, (g) replacement capital expenditures during the life of the plant, (g) the life-cycle capacity factor of the plant, and (h) the economic life of the plant. The future values of all of these variables that will be realized in practice are necessarily uncertain at the time development of a project begins. Let me say a few things about several of these cost drivers.

The overnight construction cost of a generating plant is a value that is often misunderstood. It is the hypothetical cost of a generating plant if it could be built instantly ("overnight"). The number does not reflect inflation, the costs of construction financing, or the length of time that it takes to build the plant and associated cash flows. Accordingly, the overnight cost value must be combined with assumptions about the construction period, the profile of cash flows during construction, real input price escalation during construction, financing costs, taxes, insurance and other variables to arrive at the total costs of building the plant up to the point when it enters commercial operation. Once the plant is completed, financing costs, cash flow constraints associated with debt repayment schedules, taxes, equipment replacement costs, fuel, operation and maintenance costs, insurance, and the assumed capacity factor (production of electricity per unit of capacity), are then combined to yield a pattern of expected post-construction "break-even" cash flows. The pre-construction and post-construction cash flows are combined and then discounted back to the present (or the time the project under consideration would proceed with the licensing and developing process) using the assumed post-tax weighted average cost of capital relevant to the project. This present value of future cash flows is then "levelized" over the life-cycle output of the plant in constant dollars to yield a levelized real life-cycle cost of producing a kWh of electricity for each technology. One can think of this as an annualized real life-cycle cost per kWh for each technology or, in a market context, as the real life-cycle price per kWh that the plant would have to realize in a competitive market to make it a break-even investment (just profitable enough to cover its total costs, including the opportunity cost of equity invested in the plants). Different assumptions about the overnight construction cost, financing costs, income tax rates and associated accounting procedures, capacity factors, fuel price escalation and a few other variables can have very significant effect on the results.

There has been substantial controversy over the appropriate assumptions for the overnight construction costs for nuclear plants. Unlike, pulverized coal and CCGT plants, there is no recent construction cost experience for nuclear plants in the U.S. or Europe. The nuclear plant vendors have advertised very low overnight construction cost numbers based on their own non-transparent engineering cost calculations. These projections should be viewed with some skepticism both because they are not backed up with firm financial commitments and because the nuclear industry has a poor record of forecasting construction costs (IEA 2006, page 372). Moreover, these cost estimates appear to exclude certain "owner's costs" such as engineering costs, site acquisition costs, insurance costs, spare parts inventory costs, training costs, licensing and other regulatory costs. I consider most of the recent vendor cost estimates to be implausibly low.

The MIT study made use of actual construction cost experience for recent nuclear plants completed in Japan and South Korea (MIT 2003, Appendix to Chapter 5). I have supplemented that analysis with more recent information on the reported contractual cost of the nuclear plant being built by AREVA-Siemens for TVO in Finland (which appears to exclude owner's costs and some have argued does not cover the total costs that AEVA-Siemens will actually incur), the reported cost quoted for the plant being built for Electricté de France (EDF),[8] also supplied by AREVA, to confirm what is a good base

[8] An EDF Press release issued May 4, 2006 quotes a construction cost number of 3.3 billion euros for a 1600 MWe plant or over $2,500/kW at current exchange rates. AREVA-Siemens committed to build the

case overnight cost estimate for a new nuclear plant. The number used as the base case overnight cost estimate in the MIT study was $2,000/kW in constant $2002 or about $2,300/kW in constant $2006. I believe that this is still good base case overnight construction cost estimate, recognizing that there is considerable uncertainty about what actual construction costs will turn out to be. This base case overnight cost number is much lower than the construction costs experience for nuclear plants completed in the U.S. during the 1980s and early 1990s but much higher than vendor cost forecasts.

The MIT study also made the base case assumption that new nuclear plants could be completed in five years, as does the more recent IEA study (IEA 2006, p. 365). This is below the construction periods experienced by every major nuclear power country except Japan (IEA 2006, page 373) and, I consider it to be reasonable, though perhaps on the optimistic side. The base case in the MIT study also assumed an 85% life-cycle capacity factor, though alternative cases were considered as well. The 2006 IEA study makes similar assumptions about life-cycle nuclear capacity factors. This value is lower than that assumed in most vendor presentations (e.g. 90+%), but is significantly higher than the global life-cycle capacity factors realized historically by the world's nuclear power plants.[9] In this regard, it should be noted that low capacity factors that may be associated with the "break-in" of new plants right after they are completed yield larger economic penalties in a present-value calculation than do low capacity factors late in the life of a plant. Other assumptions used in the MIT study can be found in the Appendix to

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equivalent plant in Finland for 3 billion euros, but construction delays have likely increased the actual costs of building it. AREVA has been criticized for not recovering the engineering and development costs it incurred to develop the 1600 Mw EPR in the revenues it expects to earn from these first two projects, but I think that these criticisms are unfair.

[9] A few countries, including Finland, have life-cycle capacity factors that are slightly higher than 90%, but this has not been the norm.

Chapter 5 of the MIT study (MIT 2003) and for the IEA study in Chapter 13 (IEA 2006, p. 365).

Table 1 reports estimates of the real levelized costs of nuclear plants, pulverized coal plants, and CCGT plants under a variety of different assumptions.[10] The first column reflects the assumption that the plant will be built as a stand-alone merchant project with a 40-year life. The competitive market environment in which merchant plants would be built is reflected in assumptions about the cost of equity and debt capital, the debt-equity ratio, debt repayment constraints, taxes, etc. The second column performs similar calculations for a regulated plant financed by a utility on its balance sheet using a lower cost of capital than the merchant plant and a longer amortization period. Implicit in this case is the assumption that consumers bear most of the construction cost and operating performance risks associated with the project. In both cases, we initially assume that the cost of capital for nuclear plants is higher than those for coal and gas CCGT plants due to cost, regulatory and other uncertainties.

It is evident in Table 1 that with the base case assumption about the overnight construction cost of a nuclear plant, the nuclear plant is not competitive with pulverized coal and is only competitive with CCGT generating capacity when expected real life-cycle natural gas prices are high (about $7.60/Mcf expressed in $2006 general price levels). For nuclear to be competitive with coal, overnight construction costs must fall by about 25% from the base case assumptions and financing costs must be equivalent to those for coal and CCGT plants. Thus, if nuclear is to be competitive with fossil-fuel alternatives, especially coal, construction costs must fall significantly from our base case

[10] Note that only about 3% of the electricity supplied in the U.S. relies on oil-fired generating plants. They are used primarily for peaking (low load facto) purposes.

assumptions and there must be no cost of capital premium required to finance nuclear plants. Even here, the cost saving from building a nuclear plant rather than a coal plant is quite small.

Table 2 reports the same results for the merchant case but includes prices for carbon dioxide (CO_2) emissions. The CO_2 prices vary from about \$13/ton to about \$55/ton.[11] These prices could result from the imposition of a mandatory cap and trade program as in the EU or from a tax on CO_2 emissions. Obviously, CO_2 prices burden fossil-fueled plants and make nuclear plants relatively more attractive economically. At somewhere between \$25/ton and \$50/ton CO_2, nuclear becomes economical in almost all cases unless gas prices return to low levels and even if significant reductions from the base case overnight construction cost numbers cannot be realized. It is interesting to note that it is likely that CO_2 prices within this range over the next 50 years would be necessary to stabilize CO_2 emissions by 2050 and to make carbon capture and sequestration an economical option for using coal to generate electricity (MIT Future of Coal Study, in process).

The IEA released its *World Energy Outlook 2006* in November 2006 (IEA 2006). It includes a detailed analysis of the future of nuclear power globally in Chapter 13. The focus on nuclear power in this study was stimulated by concerns about CO_2 emissions and the fact that nuclear power is an electricity supply option that generates electricity without producing significant quantities of CO_2. The results of the IEA study of the expected costs of nuclear power and associated uncertainties are reasonably similar to those in the MIT study. The expected cost per kWh from new nuclear plants varies from

[11] Note that the carbon (C) prices utilized in the MIT study have been expressed in terms of equivalent CO_2 prices here using an adjustment factor of 3.67 to reflect the differences in atomic weights of C and CO_2.

about 5.0 cents/kWh to about 8.0 cents/kWh in $2005, depending on assumptions about discount rates (cost of financing) and overnight construction costs (IEA, 2006, p. 368). The range of real levelized costs from reported in Table 1 above, after adjusting the numbers to bring them to $2005 price levels for comparability with the IEA study, are about 4.0 cents/kWh to about 7.5 cents/kWh. The IEA numbers do not include the very low construction cost case ($1500/kW) in the MIT study, so they are otherwise quite comparable. For nuclear to be competitive with coal both a low discount rate and low construction costs must be realized if there is no price place on CO_2 emissions. I do not believe that the low discount rate assumption that the IEA seems to focus on subsequently and in the summary of the chapter on nuclear power is consistent with investment by <u>private</u> firms that do not receive subsidies and pay income and property taxes in either a competitive environment or in a regulatory environment with significant construction cost and operating performance sharing incentive arrangements.

The IEA study also examines the impact of CO_2 prices on the relative economics of nuclear vs. fossil fuel alternative generating technologies. From the figures in the IEA report it looks like the impacts of CO_2 prices are qualitatively similar to those in the MIT study. With a price between $30 and $50/ton of CO_2, nuclear would be competitive with coal even with relatively high overnight construction costs and high financing costs (discount rates).

The figures in Table 1 and Table 2 and those in the IEA study, combined with uncertainty about licensing and permit approval costs and success rates, are consistent with the lack of much commercial interest by investors in new nuclear power plants in the U.S. until relatively recently.[12] In my view, the primary case for investment in new nuclear plants is that they will displace CO_2 producing generating technologies, especially coal. The combination of efforts to streamline the licensing process without sacrificing safety, financial incentives included in the Energy Policy Act of 2005, and a growing awareness of the implications of possible future U.S. policies to place a price on CO_2 emissions (e.g. passage of some variant of the McCain-Leiberman Act and continuing diffusion of individual state CO_2 mitigation policies), have been the primary contributors to a renewal of interest in investments in new nuclear plants in the U.S. However, absent significant CO_2 mitigation benefits, the economic advantages of nuclear power over coal (either PC or IGCC meeting EPA air quality standards for criteria pollutants) in the U.S. are, at best, too small to justify other baggage that comes with nuclear power: safety risks, proliferation risks, and waste disposal problems. I turn to the recent efforts to stimulate investment in new nuclear plants in the U.S. in the next section.

INSTITUTIONAL CHANGES AND FINANCIAL INCENTIVES

a. Streamlined NRC Licensing Processes

The Nuclear Regulatory Commission (NRC) has adopted new regulatory procedures to reduce the costs and delays associated with licensing new commercial nuclear plants. First, the NRC now has a process in place to certify the safety of Standard Plant Design Specifications before the associated plants are included in a specific construction and operating license application for a new plant. Once a Standard Plant Design has received safety certification from the NRC, plant developers who choose to adopt the certified plant design as approved do not (in theory) have to go through a new

[12] Unlike several countries in Europe there has never been a formal ban on building new nuclear power plants in the U.S,

plant design safety review for each specific plant seeking a construction and operating license.[13] As of November 2006, three plant designs have been certified through this process, one plant design is near the completion of the certification process, and five plant designs are in a pre-application review process at the NRC (including AREVA's EPR, the first model of which is under construction in Finland).[14]

Second, the NRC has created a new early site permitting process that permits companies to pre-license sites where they may ultimately choose to build a new nuclear plant, but can do so before the decision is made to go forward with a plant. Thus site certification can proceed and be separated from the construction and operating license process. As of November 2006 four applications have been made under this early site permitting process.[15] However, it is not necessary for a developer to go through this process. A developer can choose instead to go directly to the Combined Construction Permit and Operating License (COL) process which will include site certification.

The new COL process is the third innovation that the NRC has introduced. Under the regulatory process in place when the existing fleet of plants was built, each plant had to first go through a construction license process that involved a safety review of both the plant and the site. Once a construction permit was issued the developer could then proceed to build the plant. When the plant was completed the owner/operator then had to apply for a separate operating license. There were significant delays at each stage of this process, including delays resulting from appeals to the federal courts and resulting extensions of the evidentiary regulatory hearing process. The NRC has now created a

[13] This means that as a practical matter the U.S. will abandon the historical approach which did not rely on standardized plant designs. The U.S. has learned at least something from the French.
[14] Nuclear Energy Institute, www.nei.org accessed November 27, 2006.
[15] Ibid.

streamlined licensing approach in which a certified plant design (and an early site permit if one has been obtained) can go directly into a Combined Construction and Operating License (COL) process. Once the COL is granted the developer can proceed to build the plant. When it is completed the NRC then would perform a series of inspections, verifications, tests and analysis to confirm that the plant was built in accordance with all COL license criteria. A second regulatory proceeding to review a separate application for an operating license would not be required.

In theory, this new regulatory process should reduce licensing costs and delays. However, the COL process has not been tested as no proposed plants have yet gone through it from beginning to end. Accordingly, how well it will work in practice, and how it will be affected by hostile intervenors in the licensing process and appeals to the federal courts is very uncertain. The first few proposed plants that actually go through the COL process with a plant that meets the pre-approved Standard Design Specifications will teach us a lot about the duration and costs of this new licensing process. Indeed, the first plants through this process will provide valuable information to all potential investors in nuclear plants, but there is no obvious way for them to appropriate the value of this information to help them to cover any "first of a kind" regulatory costs they incur by being the first projects that go through the new regulatory process.

b. Financial Incentives in the Energy Policy Act of 2005

I think that it is fair to say that prior to the passage of the Energy Policy Act of 2005 ("the Act"), investors were not exactly beating down the door of the NRC to file applications of Early Site Permits or COLs. However, the Act provides a number of significant financial incentives to the first few plants that enter the COL process, are built and ultimately begin to operate. These incentives, combined with rising fossil fuel costs, rising wholesale market prices, and growing recognition that CO_2 prices may be imposed at some point within the life of a new plant that enters construction today, have stimulated much more serious interest among investors in building new nuclear plants.

The Act provides for a 1.8 cent/kWh investment tax credit for new nuclear capacity during its first 8 years of operation. This subsidy is limited to no more than $125 million per year per 1,000 Mw of capacity and no more that 6,000 Mw of new capacity can receive this subsidy. In addition, new nuclear plants are eligible to apply for loan guarantees for up to 80% of a plant's construction cost. These loan guarantees will reduce the cost of debt financing for projects that receive them and allow the financing of the projects to be more highly leveraged. These subsidies reduce the life-cycle costs of a new nuclear plant by on the order of $20/Mwh, assuming that they operate with 85% capacity factors (IEA, p. 376).[16] The Act also provides "insurance" against regulatory delays for the first 6,000 Mw of new capacity that applies for a COL. The first two plants are eligible for up to $500 million of payments for the costs of regulatory delay and the next four plants for up to $250 million each. The details of how much in loan guarantees will actually be made available by the federal government (all generating plants that do not produce greenhouse gases are eligible), how investment tax credits will be allocated if more than 6,000 Mw of new capacity enters service during the eligibility window specified in the Act, and how the costs of regulatory delay will be determined are yet to be specified by the federal government.

[16] My colleagues at MIT have derived estimates of the aggregate value of the subsidy that are only slightly smaller.

The rationale for these financial incentives is that there are "first mover costs," including potential costs of regulatory delays, that are acting as barriers to restarting construction of new nuclear plants and allowing the development of new nuclear designs to move down a learning curve to realize cost savings. According to this theory, by subsidizing the first 6,000 Mw of new capacity, the direct costs of construction and uncertainty about the speed and costs of the regulatory process will fall and nuclear investment will then be economic without further special subsidies. It is a "learning by doing" type of justification.

Since the passage of the Act, intentions to pursue roughly two-dozen new nuclear plants have been "announced" by individual generating companies or consortia of generating companies.[17] Many of these companies have substantial nuclear operating experience. However, announcing the intention to pursue a project and actually making a significant financial commitment to proceed with a COL and construction once it is granted are not the same thing. No applications for COLs have yet been made and as far as I know there have been no firm contracts consummated to purchase equipment and construction services from nuclear equipment suppliers and construction companies. The first COL applications are forecast for late in 2007 and this suggests that it is unlikely that any new nuclear capacity will enter service much before 2015.

Clearly, a subsidy of about $20/Mwh plus insurance against the costs of regulatory delay is a significant incentive for nuclear plant investments that are eligible to receive the subsidy. It is equivalent to placing a price of about $25/ton of CO_2 emissions from pulverized coal plants. However, since the subsidies are available for only the first 6,000 Mw of new nuclear capacity, the long term effects of the program on investment in

[17] Nuclear Energy Institute web site http://www.nei.org accessed November 18, 2006.

nuclear capacity will depend on (a) the industry being able credibly to reduce construction costs to a level significantly below $2,300/kW ($2006), (b) to keep construction time at 5 years or less, or (c) for the federal government to introduce a program that places a price on CO_2 emissions of at least $25/ton of CO_2.

These conclusions are consistent with the EIA's forecasts of investment in new nuclear plants between 2005 and 2030 contained in its 2006 *Annual Energy Outlook* (IEA AEO 2006, pp. 79-80). The EIA reference case (which does not place a price on CO_2 emissions) reflects the subsidies included in the Act and projects 6,000 Mw of new nuclear capacity by 2030. The results for the reference case suggest that these nuclear subsidies make the 6,000 Mw they apply to economical investments, but that nuclear plant construction costs do not fall fast enough to make further post-subsidy nuclear plant investment economical.[18] If this result is realized in reality it would suggest that the subsidy program had failed to achieve its primary "learning by doing" goals. The EIA's 2006 AEO also presents results for two alternative cases. The first case reduces the construction costs of new nuclear plants by 20% from the reference case values (roughly consistent with the low construction cost case in the MIT study). With a 20% construction cost reduction, about 34,000 Mw of new nuclear capacity enters service by 2030 (IEA AEO 2006, p. 84). I consider this to be a challenging but possible result to achieve. Finally, the EIA 2006 AEO contains a "vendor cost goal" case that requires an average reduction in construction costs from the reference case of 35%, falling to a 44% reduction by 2030 (IEA AEO 2006, p. 84). This case yields 77,000 Mw of new nuclear capacity by 2030. I consider the cost reduction assumptions in this case to be implausible. However, a cost reduction of 20% plus a carbon dioxide emissions price of about \$25/ton CO_2 could yield a similar result.

Before concluding this section, there is one observation that I want to make about "national security" rationales for nuclear power that appear frequently in the media and are sometimes exploited by nuclear power proponents. First, almost no oil is used to generate electricity in the U.S. and this fact is not likely to change in the future. Second, in the EIA AEO 2006 scenarios discussed above, new nuclear plants primarily are substitutes for new coal plants. As a result, the investment in nuclear capacity does not have a significant impact on imports of oil or liquefied natural gas (LNG), which is forecast to grow rapidly over this period. Accordingly, there does not appear to be an "energy security" case for investment in new nuclear plants. As I have already indicated, I believe that the primary policy rationale for providing special subsidies to "first mover" nuclear power plants is to maintain nuclear power as an option for generating electricity that would support a U.S. policy to reduce CO_2 emissions that would otherwise be produced from coal burning power plants.

OTHER POTENTIAL INSTITUTIONAL BARRIERS

There are other potential institutional barriers to a significant growth in new nuclear capacity that need to be taken into account. First, the unsettled state of electricity sector restructuring and deregulation (Joskow 2006a) suggests to me that it is unlikely that we will see much if any investment in new nuclear capacity in states that have adopted competitive market models, at least until wholesale and retail market designs deal with design flaws that create general disincentives for investment in new generating capacity (Joskow 2006b). Moreover, stabilizing wholesale and retail market designs so that investors can count on a clear, stable, and fair market environment will need to occur to support this type of investment. Second, potential investors in new nuclear plants will still have to deal with state and local regulatory authorities and potential resistance from anti-nuclear groups that have been quiet during the long hiatus in new nuclear plant construction. Historically, the greatest opposition to nuclear plants has been in the Northeast and the West Coast, especially California.[19] Many of the states that have adopted competitive market models also happen to be located in these regions of the country.

The current state of competitive electricity markets in the U.S. combined with local opposition to new nuclear plants is not an attractive combination for potential investors. (Ironically, the economics of nuclear investment are quite promising in New England, New York, New Jersey, California and Texas because existing natural gas fueled generation is on the margin in many hours of the year and, as a result, wholesale prices are quite high there.) On the other hand, there are many existing nuclear plant sites, including in states which have not adopted competitive electricity market models, that were designed to accommodate more nuclear plants than were actually built on these sites. There is room to build additional nuclear capacity on several of these sites. In most cases, the residents in the areas near these sites have come to accept nuclear power plants and, indeed, to enjoy the property tax revenue that they produce. They are likely to be favorably disposed to investments to expand capacity on at least some of these existing sites.

[19] Of course it is possible that the current concerns about CO_2 emissions will make groups that historically opposed nuclear power more favorably disposed towards it now, and there is some evidence that environmental groups have moved in this direction.

The final potential institutional barrier to significant investment in new nuclear capacity in the U.S. is the continued inability of the federal government to fulfill its commitment to take back spent nuclear fuel and to provide for its safe long-term storage and disposal. The progress on getting the Yucca Mountain site licensed to receive spent fuel continues to be subject to delays and it is opposed by powerful politicians in Nevada. While investment in new nuclear plants might proceed without a complete resolution of waste disposal issues, unless credible interim and final waste disposal institutions are placed into operation, it may create significant investor disincentives and public opposition to a major program of nuclear expansion.

CONCLUSIONS

The future for investment in new nuclear plants in the U.S. is brighter than it has been for many years. The support and subsidies from the federal government contained in the Energy Policy Act of 2005 and the earlier reforms in the federal licensing process have given the nuclear industry what it says it needs to "get over the hump" and stimulate a significant program of investment in new nuclear power plants. It's now up to the industry to deliver on its claims about construction costs, operating performance, and financing costs.

All things considered, I believe that investment in new nuclear plants is likely to proceed more slowly than may be implied by the recent euphoria in the industry. I believe that projects are most likely to proceed (a) on existing sites, (b) in states that have not adopted competitive market models, and (c) where there is support from local authorities. Among the competitive states, Texas is the most likely candidate for investment in new nuclear plants for both economic and political reasons. A nuclear investment program will be larger and proceed more quickly if the nuclear equipment vendors and the construction firms are willing to take on more of the construction cost and operating performance risk than they did during the 1980s, at least until the first dozen of so plants are completed and credible information about construction costs, construction time, and regulatory costs and delays have been confirmed by actual experience rather than hypothetical spreadsheet calculations. Finally, if the U.S. adopts a cap and trade program for CO2 emissions that yield prices in the range of $25 to $50/ton of CO_2, it will make investment in new nuclear power plants much more attractive financially than it is today, especially after the 2005 Act's subsidies are exhausted.

TABLE 1

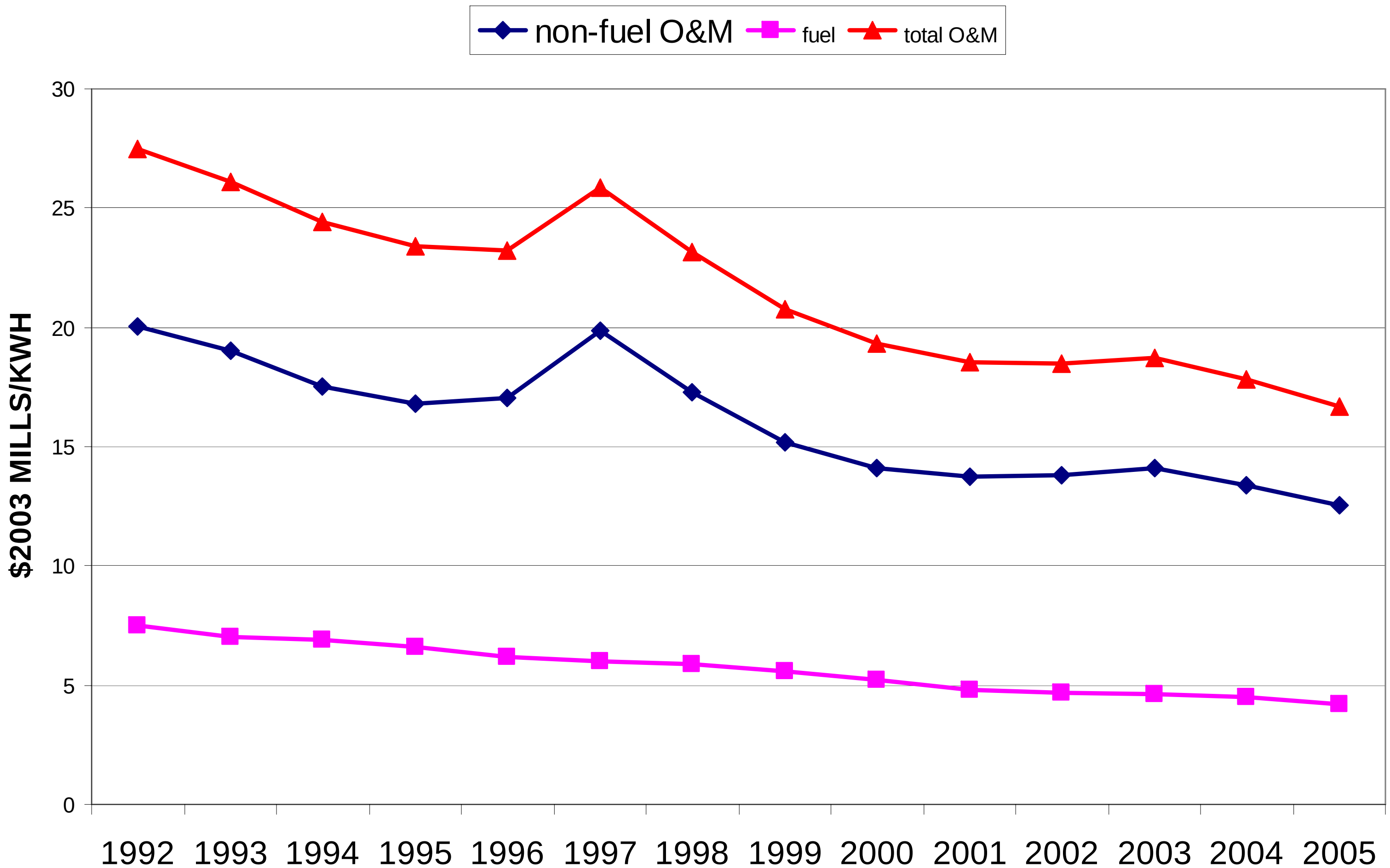
Comparative Base Load Real Levelized Costs
$2002 cents/kWh

	Merchant Financing Model[20]	Traditional Regulatory Model[21]
Nuclear Cases		
Base Case ($2000/kW)	6.7	5.2
25% Lower Construction Costs ($1500/kW)	5.5	4.4
Reduce Construction time By 12 months (4 years)	5.3	3.6
Reduce financing costs to Equivalent coal and CCGT	4.2	3.6
Pulverized Coal	4.2	3.5
Gas CCGT Cases		
Low gas prices ($3.77/Mcf)	3.8	3.6
Moderate gas prices ($4.42/Mcf)	4.1	4.0
High gas prices ($6.72/Mcf)	5.6	5.7

[20] MIT (2003), p. 42 and Appendix to Chapter 5. In the merchant case the plant owner bears all construction cost, operating performance and market risk.
[21] Author's calculations. In the traditional regulated case consumers bear the costs or benefits of all "prudent" construction cost overruns, operating performance variations, and changes in market values.

FIGURE 1

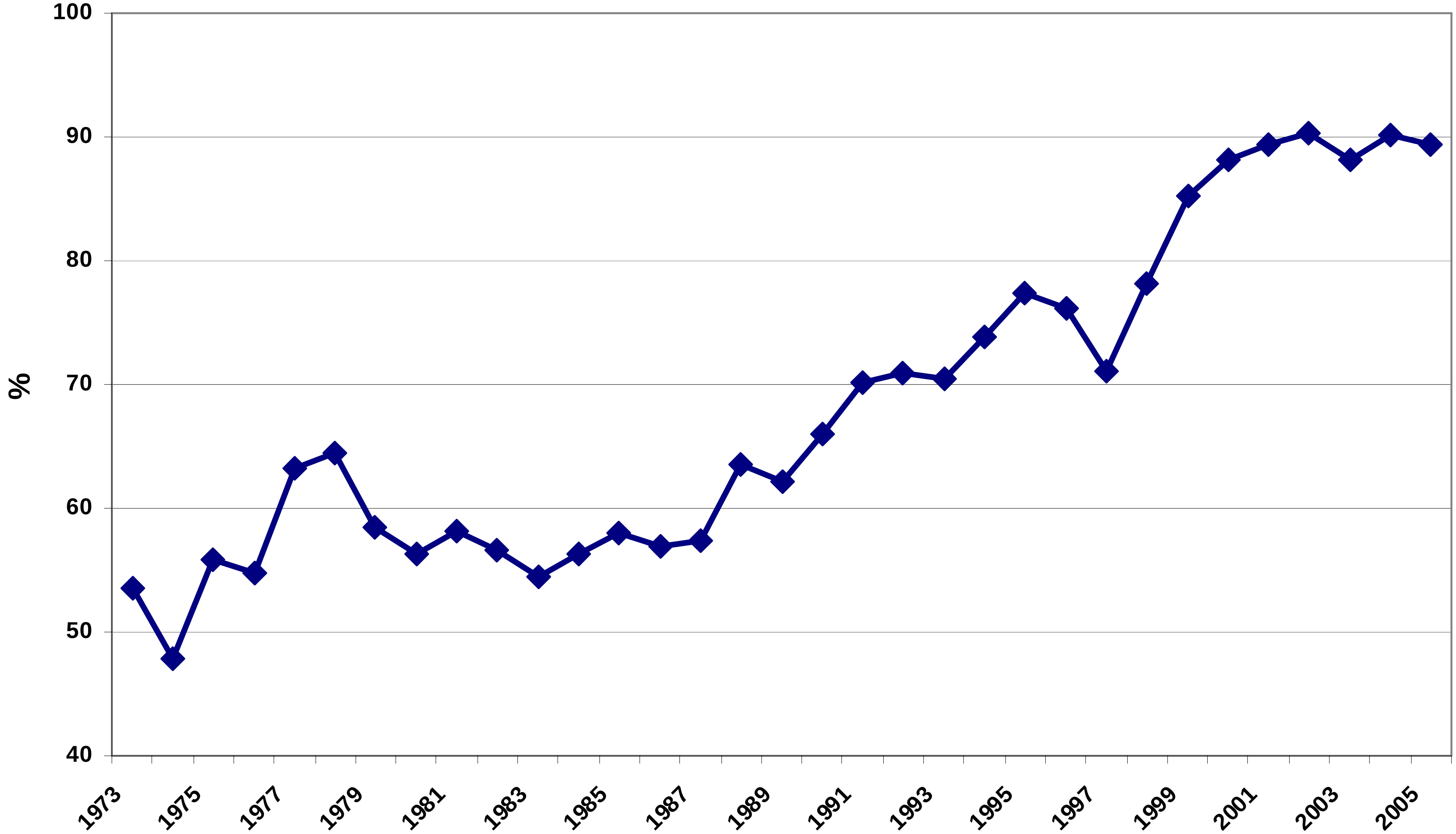
REAL NUCLEAR O&M COSTS ($2003 MILLS/KWH)



Source: EIA Electric Power Annual various years

FIGURE 2

U.S. NUCLEAR PLANT CAPACITY FACTORS
1973-2005



Source: EIA AER 2005

TABLE 2

Effects of CO_2 Prices on Real Levelized Cost of Electricity
Merchant Financing Model
($2002 cents/kWh)[22]

	$0/ton CO_2	$13.50/ton CO_2	$27/ton CO_2	$54/ton CO_2
Pulverized Coal	4.2	5.4	6.6	9.0
CCGT High Gas Price	5.6	6.1	6.7	7.7
Nuclear Cases				
Base Case	6.7	6.7	6.7	6.7
-25% Construction Cost Case	5.5	5.5	5.5	5.5
Lowest cost Case	4.2	4.2	4.2	4.2

[22] See Table 1 for the $0/ton CO_2 case. For the other cases see MIT (2003), page 42 and appendix to Chapter 5. Note that carbon prices expressed in $US(2002) per metric ton of carbon in the MIT Report have been express in $US(2002) per metric ton of CO_2 here by dividing by 3.67 for easier comparisons with other studies.

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